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Long-baseline universal matter-wave interferometry

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Abstract:

Matter-wave interference is evidence for a coherent splitting and recombination of a particle's wavefunction, and thus provides an excellent testbed for confirming quantum mechanics in new regimes. Matter-wave interferometers are also extremely sensitive measurement devices and have made impressive headway in measuring gravity, gravity gradients, and rotation, as well as fundamental constants.

This thesis describes the construction and initial results of a new matter-wave interferometer, the Long-baseline Universal Matter-wave Interferometer (LUMI). LUMI relies on the near-field Talbot-Lau effect, which has several advantages for molecule interference experiments, including good scalability to high-mass particles, low coherence requirements, and a high throughput. The interferometer contains two nano-fabricated material gratings and a central grating which can be interchanged in situ between another material grating or an optical phase grating. This modularity enables experiments with a wide range of particle species, from atoms to complex molecules to metal clusters. The separation between each grating is one meter, which enables interferometry in a higher mass regime than previous experiments. The long baseline required the development of experimental techniques to compensate the dephasing effects of the Coriolis force and grating vibrations.

Results shown in this thesis demonstrate high fidelity interference of macromolecules beyond 25,000 atomic mass units and composed of up to 2000 atoms. These experiments represent a new record in superposition macroscopicity and place new bounds on the parameter space of proposed collapse models which aim to describe the transition from a quantum to classical regime.

The universality of the interferometer scheme, combined with its inherent high force sensitivity, makes LUMI well suited to probing a range of atomic and molecular properties. Information about the material properties is encoded in the response of the interference fringes to an external field. An improved measurement of the static polarizability of fullerenes is demonstrated, as well as a direct measurement of the ground state diamagnetic susceptibility of isolated barium and strontium atoms. Measurements of the electric susceptibility of functionalized tripeptides are also described, as well as the implementation of a magnetic gradient for studying atoms and molecules with permanent magnetic moments.

Finally, an outlook is provided for the planned upgrade to the LUMI experiment which will enable interferometry of masses beyond 100,000 atomic mass units.